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DESCRIPTION TO INVENTOR'S CERTIFICATE

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(53) 621.385.833 (088.8)
(56) D. Binning and G. Rorer, "The scanning tunneling microscope," V Mire Nauki [World of Science], No. 1, .6 (1985).
D. Binning and D. Smith. Tubular Three-Directional Piezo-Transducer for a Scanning Tunneling Microscope.- Instruments for Scientific Research, 1986, p. 152

(54) SCANNING TUNNELING MICROSCOPE

(57) The present invention relates to tunneling electronic microscopy and may find use in instruments for research of physical properties of solid-body surfaces with resolution capacity on the order of atoms. It is an object of the present invention to improve the sensitivity of a microscope and to increase the field of scanning by reducing the effect of vibratory disturbances and by independently adjusting control voltages applied to piezo-elements in the system of displacement of the measurement cantilever and the specimen. The scanning tunneling microscope comprises two tubular piezo-elements identical in the shape and dimensions, which are arranged coaxially to each other and are fixed in the housing at their opposite end faces. Located on the mating end faces are specimen and cantilever holders, which are arranged opposite to each other and have a mass difference not exceeding 0.24 of the mass of the tubular piezo-element. 1 drawing, 1 table.

The present invention relates to tunneling electronic microscopy and may find use in instruments for studying physical properties of solid-body surfaces with resolution capacity of the order of dimensions of atoms. In particular, the invention may be used for studying the atomic structure of solid bodies, electronic properties of the solid bodies on the atomic scale, processes of adsorption and surface diffusion of atoms, molecules, and sub-microscopic objects, as well as of biological processes. The invention is also applicable for control of microelectronic products.

It is an object of the invention to improve sensitivity of a microscope and to increase the scanning field by reducing the effect of vibrations and by independently adjusting control voltages applied to piezo-elements of the system responsible for displacement of the measurement cantilever and specimen.

A structural scheme of a tunneling cell of the microscope is shown in the attached drawing.

All parts of the scanning tunneling microscope

are secured in a rigid housing 1. Identical tubular piezo-elements 2 and 3, made from a piezo-ceramic material with controlled electrodes applied onto them, are arranged coaxially to each other, and their opposite end faces are secured in the housing of the device.

The mating free ends of the first piezo-element 2 and the second piezo-element 3 support identical sleeves 4 secured in which are a cylindrical holder 5 of a measurement cantilever 6 and a cylindrical holder 7 of a specimen 8, respectively. The sleeves 4 are produced, e.g., in the form of collet chucks with spring-loaded tongues that embrace the cylindrical holders. The holders 5 and 7 are made so that their masses do not exceed 0.24 of the mass of the piezo-elements.

The scanning tunneling microscope operates as follows.

A gap ranging from 0.1 to 1.0 μm is preliminarily established between the specimen 8 and the measurement cantilever 6. Then, under the effect of a control voltage U_z that is applied to the electrodes of the first piezo-element 2 and causes elongation or shortening of the latter (depending on the sign of the applied voltage), the cantilever and the specimen further approach each other, and, when the gap between both parts reaches several Angstroms, this causes the generation of a tunneling current which is then maintained at a predetermined level by the circuit of automatic control.

Scanning in the directions of the X and Y axes is carried out by applying control voltages in the respective directions by lines and frames. The use of two identical tubular piezo-elements makes it possible to employ one of them for scanning the cantilever in the X-Y planes, while the other one is utilized for presetting a relative movement between the cantilever and the specimen in the Z-axis direction. This allows variation of each control voltage over the entire range, i.e., the scanning field dimensions are increased by a factor of 2 to 3 as compared with a conventional microscope of this type.

However, in contrast to the measurement cantilever, which has a negligently small mass, the specimen holder normally has mass m_{sh} comparable with or greater than the mass $m_{p.e.}$ of the piezo-element.

In this case, an analysis of the effect of external vibrations on sensitivity of the microscope reveals the following.

Vibrations cause mutual displacement between the specimen and the measurement cantilever which results in a signal noise. Vibration frequencies ν_{vibr} normally range from 10 to 100 Hz, and amplitudes range from 1 to 10μm. Inherent frequencies ν_{inh} of the elements of scanning tunneling microscopes fall into the range of 1 to 100. Thus, the following condition is always satisfied: $\nu_{vibr} << \nu_{inh}$. Under this condition, the amplitudes of mutual oscillations of the instrument parts are reduced by (ν_{inh}/ν_{vibr}) times as compared to the amplitude of oscillations of the instrument housing. Similarly to the known scanning tunneling microscope, in the proposed microscope, the signal noise is caused by flexural oscillations of the tubular piezo-elements that have the minimal inherent oscillations. For example, the minimal inherent frequency of flexural oscillations of the tubular piezo-element, which in the case of our invention is loaded only by the cantilever having a negligibly small mass, is equal to 7 kHz. In other words, spectral components of the vibrations with the amplitude of 1 μm and frequency of 100 Hz are attenuated to the level of about 0.2 nm, which is insufficient for measurements with atomic-level resolution capacity. The formula for determining the minimal frequency of inherent oscillations of the tube can be converted into the following form:

$$\nu_{co6c} = \frac{1}{2\pi}\sqrt{\frac{K}{0,24m_{n.э}}}$$

wherein K is flexural rigidity;

ν_{co6c} stands for ν_{inh};

$m_{n.э}$ stands for $m_{p.e}$, which is a complete mass, in this case, of the tubular piezo-element.

If the end of the piezo-element supports a compact specimen holder with mass $m_{s.h.}$, then the formula is converted into the following expression:

$$\nu'_{\text{соб}} = \frac{1}{2\pi}\,\frac{K}{m_{\text{д.о}}+0,24m_{\text{п.э}}},$$

In other words, because the following condition is fulfilled: $\nu_{vibr} << \nu_{inh.}$, at $m_{s.h.}$= 7.0 g the amplitude of the vibration will increase by the factor of

$$\left(\frac{m_{\text{д.о}}+0,24m_{\text{п.э}}}{0,24m_{\text{п.э}}}\right)$$

i.e., 4 times, whereby the specimen and the cantilever will oscillate in phase with each other since they oscillate in phase also with the external factor (a small phase shift in oscillations of the holders relative to the instrument bed which is equal to $\gamma\nu_{vibr} << \nu_{inh.}$, wherein γ is a decrement of the attenuation of free oscillations which is too small for piezo-elements, i.e., $\gamma/2\pi\nu_{inh.} \leq 10^{-2}$ to 10^{-3}, is neglected). Therefore, for identical piezo-elements, the amplitude of relative oscillations of the specimen and the cantilever is

$$\frac{m_{\text{д.о}}-m_{\text{д.и}}}{0,24m_{\text{п.э}}}$$

of the amplitude of cantilever oscillations in the conventional microscope and thus at

$$(m_{\text{д.о}}-m_{\text{д.и}}) < 0,24m_{\text{п.э}}$$

will become less than in the conventional microscope, i.e., a positive result will be achieved. If the holders themselves have the same mass, then in a first approximation, a difference between the oscillation amplitudes of the cantilever and the specimen is determined by the mass of the latter, and since in a real construction the mass thereof at the dimensions of the aforementioned scanning tunneling microscope corresponds approximately to fractions of one gram, attenuation of vibrations will be significant.

E x a m p l e. The scanning tunneling microscope manufactured by the inventors herein contained tubular piezo-elements having a 10 mm external diameter, 32 mm in length, 1mm wall thickness, and mass $m_{p.e.}$ = 8 g.

The piezo-elements were provided with continuous cylindrical internal and external electrodes. In the second piezo-element 3, the external electrode was cut along the generatrix into four identical sector-shaped electrodes which were isolated from each other. Control voltage U_z was applied to the first piezo-element 2, and control voltages U_x (U_y) were applied to orthogonally arranged pairs of sector-shaped electrodes. The cantilever holders withstood an electric field having the intensity of 10 kV/cm, which allowed a change of voltages U_x (U_y) in the range of ±2 kV and provided the 40 x 40 μm^2 scanning range in the X-Y plane, which is 2 to 3 times greater than with the use of a conventional microscope.

Sensitivity is measured by means of a noise signal of the scanning tunneling microscope and for the measurement time of 1 sec., it was equal to 0.02 nm.

The table shown below presents data that show the effect of the holder mass difference on sensitivity of the scanning tunneling microscope under real laboratory conditions when the flow vibration amplitude was 1 µm, and frequency was 100 Hz (measured by seismograph).

As can be seen from the above example, the scanning tunneling microscope of the invention possesses sensitivity that is10 to 20 times higher than that of a conventional one.

PATENT C L A I M S

1.A scanning tunneling microscope comprising: a housing; a tubular piezo-element, one end face of which is secured in the housing, while the other end face supports a holder of a measurement cantilever; a specimen holder;

and control system; the microscope being characterized by the fact that, in order to improve the sensitivity of the microscope and to increase the scanning field, it further comprises a second tubular piezo-element, which is identical to the first one in its shape and dimensions, and which is arranged coaxially with the first piezo-element and is secured at one end face thereof in the housing, while the specimen holder is supported by the free end of the second piezo-element, wherein the mass difference of the holders does not exceed 0.24 of the mass of the tubular piezo-element.

Table

Microscope	Mass of Piezo-Element, g	Mass of cantilever Holder, g	Mass of Specimen Holder, g	Sensitivity, nm
Conventional	8	0.01	- -	0.172
According to invention	8	1.5	7.0 69*	0.48
	8	5.08	7.0 24	0.17
	8	5.4	7.0 20	0.15
	8	7	7.1 1.2	0.009

**Translator's Note 1: The Russian original does not identify to what characteristic this column of the table belongs. It is possible that this is the mass of the piezo-element and that the one of the columns in the table was not printed and/or the Russian text is misaligned.*

** Translators Note 2:The Russian abbreviation "co6cm" in the equations stands for "inherent" ("inh.").*

[Drawing]

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